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ALBA Synchrotron Cooling System Evaluation Using Flowmaster®

After five years in operation, the ALBA Synchrotron Light Source realize the first upgrade process of its cooling system.

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Figure 1. Alba 3rd Generation Synchrotron Light Facility in Barcelona, Spain

ALBA is a 3rd generation Synchrotron Light facility in Barcelona, Spain. Made up of a complex network of electron accelerators that produce synchrotron light, it allows for the visualization of the atomic structure of matter as well as the study of its properties.

The 3 GeV electron beam energy at ALBA is achieved by powerful combinations of a LInear ACcelerator (LINAC) and a low-emittance, full-energy BOOSTER located in the same tunnel as the STORAGE RING. ALBA's 270 meter perimeter has 17 straight sections all of which are used for the installation of insertion devices.
ALBA currently has seven operational state-of-the-art phase-I beamlines, comprising soft and hard X-rays, which are devoted mainly to biosciences, condensed matter (magnetic and electronic properties, nanoscience), and materials science. Additionally, two phase-II beamlines are in construction (infrared microspectroscopy and low-energy ultra-high-resolution angular photoemission for complex materials).

This large scientific infrastructure provides more than 5,000 hours of beam time per year for the academic and the industrial sector, serving over 1,000 researchers every year.

ALBA is a facility committed to scientific excellence and to improving the well-being and progress of society as a whole.

After five years in operation, the ALBA Synchrotron Light Source has realized the first upgrade process of its cooling system. The main objective of the project was to enhance the hydraulic plant and its control system. Specifically, this enhancement is expected to significantly improve the

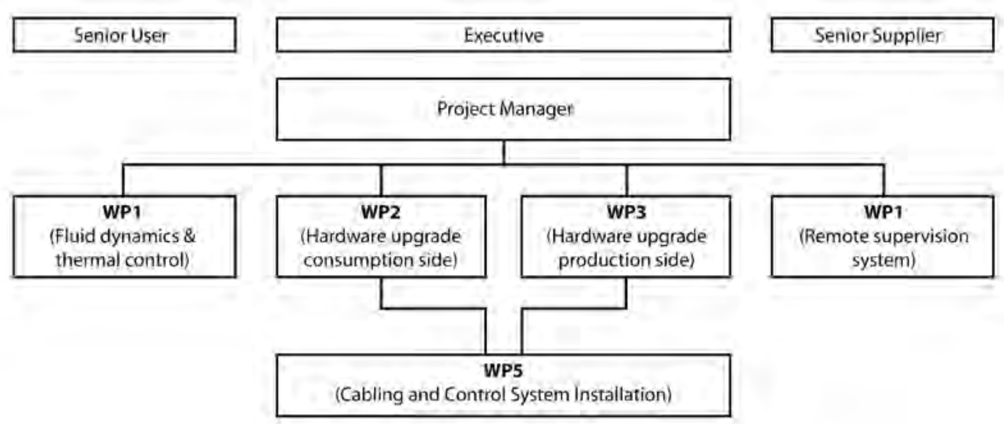

Figure 1. Organization of work packages for the project "ALBA Cooling System Upgrade".

facility's reliability by providing more protection against single point failure, its stability as a result of more robust in-front-of-load variations and/or external perturbations, and tolerability in fail mode to ensure maximum service readiness.
To embark on this objective a Project Manager structure was defined and all the activities were grouped in the following five work packages (WP) as detailed in Figure 1. This article will focus on Work Package 1 (WP1) which set out to better understand the cooling system from a fluid dynamics control point of view.

The ALBA Cooling System

The ALBA cooling system is outlined on the left of Figure 2 and comprises two main parts: production and consumption. For the purposes of this article, the focus will be mainly on the consumption side which is composed of four rings that require refrigeration. They are named Experimental Area (EA), Service Area (SA), Storage Ring (SR), and Booster (BO) as indicated on the right of Figure 2. Both the Storage and the Service Area rings operate with a pair of twin-pumps mounted in parallel and the rest with a single pump. The deionized water is heated through all the rings and is collected in a common return line. Another pump (P11) takes the heated water from the return and feeds heat exchangers that cool it. The cooled water is brought to a large volume accumulator from which a suction line takes water again to the rings' pumps. In order to regulate the water temperature, a series of controlled mixing valves allow for the combination of the cooled and heated water to take place, prior to being pumped to the rings. Moreover, a pressure maintenance system with a compressor is mounted at the exit line of the heat exchangers before the accumulator. Finally, a pipe line connecting the accumulator with the common return line enables the compensation for the lack or excess of flow to the cooling loop when the total flow rate changes in the rings' loops.

The Rings Model

As can be seen in Figure 2, each ring (EA, BO, SR and EA) consists of two concentric ring-shaped pipelines (inlet and return flow) that refrigerate a specific number of sub-systems. At the same time, most of these sub-systems are made up of additional sub-networks that supply the cooled deionised water to final consumptions.

Currently, Experimental Area Ring feeds nine sub-systems, seven of which correspond to Beam Lines (each Beam Line has various components to refrigerate) and the rest are provisional by-passes. The Booster Ring has 104 sub-systems. One of them is a Radiofrequency Cavity (RF) that refrigerates 14 components by the means of a manifold. The remaining 103 sub-systems are single electromagnets which are present in eight variations. With regards to the Storage Ring's sub-systems, 21 are different types of electromagnets (8 to 17 magnets are fed by each sub-system), ten are Front Ends (each one cools one to five consumptions), and three correspond to RFs Cavities. In relation to the Service Area Ring's sub-systems, nine supply cold water to Power Supplies, one feeds the LINAC and some Power Supplies and the last four sub-systems are connected to RFs Plants.

The rings' models have been built up from the available components in Flowmaster

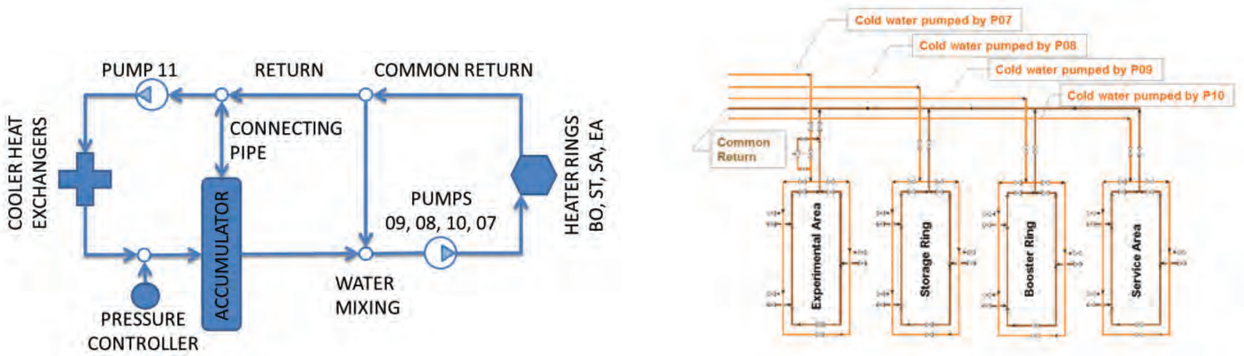

Figure 2. Outline of the cooling system (left) and of the consumption side (right)

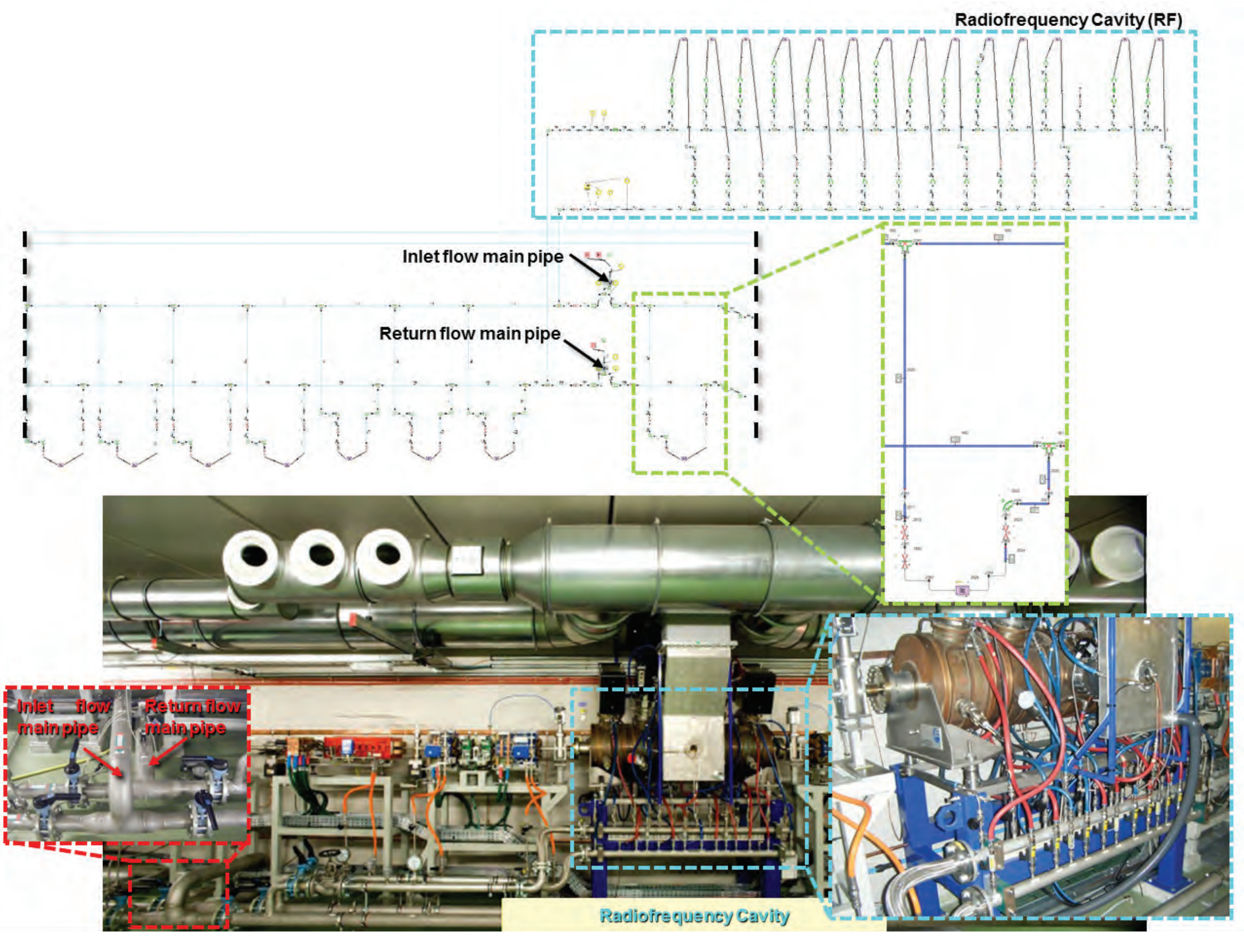

Figure 3. Comparison between a section of the Booster Ring (bottom) and its modeling (top)

software. The properties of each component have been selected based on the information provided by the corresponding manufacturer in the form of construction planes, technical documentation and so on. The lack of reliable information has been overcome with visual inspections and measurements in-situ. However, for the current study such level of detail has not been achieved on each ring due to their dense and complex structure as well as owing to the lack of time. As a result, the selected rings' sub-systems to model with detail, according to the needs of the ALBA Synchrotron, are as follows.

The completely modeled sub-system of the Experimental Area Ring is one Beam Line (BL). Nevertheless, the by-pass piping networks for two future BLs have also been modeled, and the remainder ignored. The different consumptions of these BLs have been simplified with a unique heat exchanger.

When considering the Booster Ring's sub-systems, all have been modeled down to the last detail. For instance, the top of Figure 3 shows the modeling of the two main pipes of the Booster Ring and nine of its sub-systems (eight electromagnets and the RF Cavity); with bottom of Figure 3 depicting this section. Another example is the model of the RF Cavity which is shown in Figure 4 where we can see the configuration of the manifold which supplies water to 14 local consumptions.

In contrast, the Storage Ring's fully modeled sub-systems are only four: one is the secondary distributor at sector 15 (which is grouping 16 electromagnets) and the other three are RFs cavities. Again, the geometry of the pipelines of the rest of the sub-systems has not been considered. In addition, the combination from one to five consumptions of each Front End has been modeled with a single heat exchanger. Despite this, a characterized heat exchanger element models each one of the various consumptions fed by the rest of the simplified sub-systems.

The Service Area Ring's are two detailed sub-systems: the RF Plant at sector 14 (see

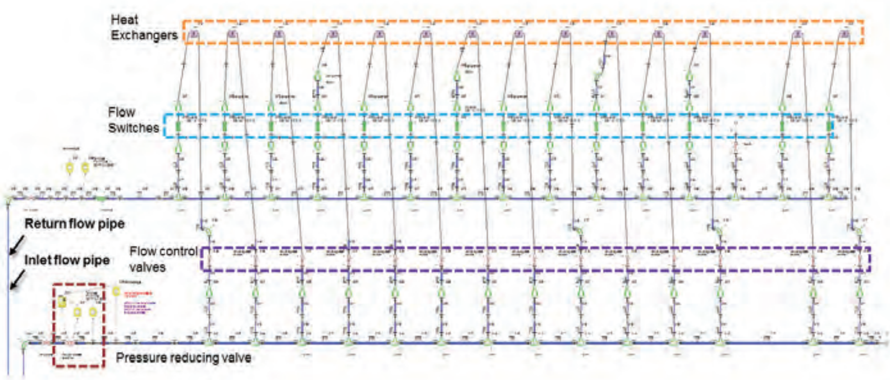

Figure 4. Schematic of the Radiofrequency Cavity of the Booster Ring

blue highlighted zoom of Figure 5) and the sub-system that combines the LINAC and some Power Supplies. A duly characterized heat exchanger element models each one of the different consumptions of these two sub-systems. Once again, the geometry of the other two RFs' manifold and of the pipelines of the rest of the sub-systems has not been modeled. A heat exchanger emulates not only the two simplified RFs' components but also the combination of Racks refrigerated by each one of the rest of the sub-systems (see green highlighted zoom of Figure 5). The contrast between the detailed and simplified sub-systems can be observed in Figure 5. Furthermore, Figure 6 demonstrates how meticulous the modeling of one RF's consumption is.

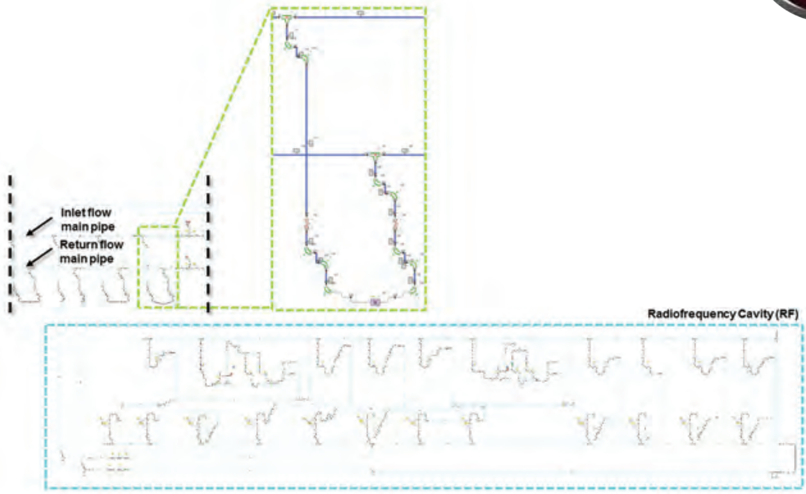

Figure 5. Schematic of a section of the Service Area ring model

Improving Pipe Velocity Distribution

Originally, the four rings had the same flow distribution: (i) the inlet flow was equally distributed to the left and right branch through a T-junction, by opening the two exit valves so that they tend to converge towards the opposite 180º ring location; (ii) for the return flow, the directions were reversed and two flows tend to converge towards the main outlet pipe. This original flow distribution is indicated as "180º circulation" on the left of Figure 7. This configuration causes the reduction of the flow velocities, as the two inlet flows approach and a zero velocity point should be ideally achieved in some undefined location which is dependent on the local consumption distributions. Consequently, there is a risk of air accumulation in a zone that might be close to some critical

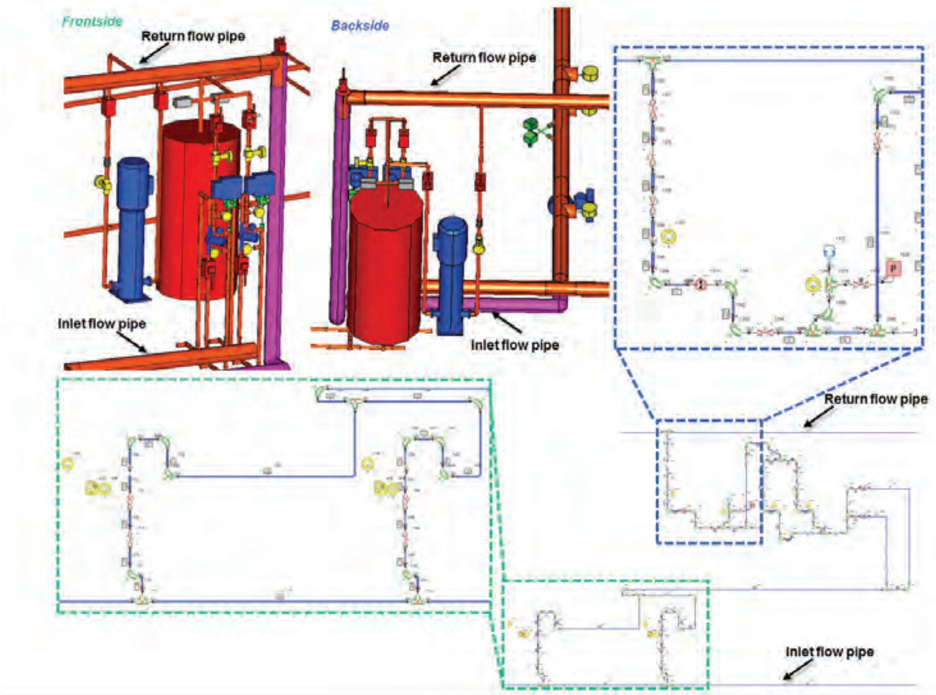

Figure 6. Comparison between the real appearance (CAD pictures) and Flowmaster modeling of one the RF's consumption

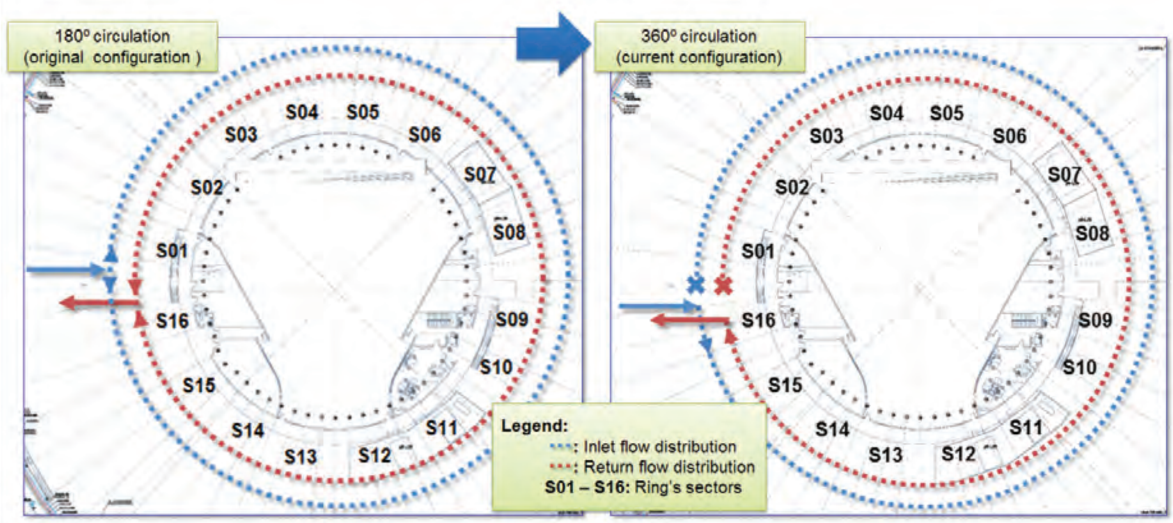

Figure 7. Schematic of the 180º original flow distribution (left) and of the 360º current flow distribution (right) at Experimental Area ring.

sub-system. In order to improve the flow velocity distribution along the rings, it was considered to change the position of the valves by closing one valve of the T-junction exit branches and to force a 360º circulation as indicated on the right of Figure 7. According to the opening or closing of T-junction exit valves, it is possible to distinguish a total of five flow distributions in each ring (one of 180º and four of 360º circulations) as observed in Table 1.

In summary, the Flowmaster software has been used to simulate all the possible configurations with the aim of establishing the existence of an optimal flow distribution that minimizes the locations with the lowest velocities.

Accuracy of the Model

A preliminary validation of the Flowmaster model has been carried out with the production side comprising the pumping units. For that, the simulated results have been compared with the real hydraulic variables like flow rates (Q), pump rotating speeds (*n*) and pump delivery pressures (*Pimp*). Table 2 shows the comparative studies for a real working point of the cooling system. For the overall variables of the hydraulic system, the maximum average deviation equals – 6.8% corresponding to pump rotating speeds. The deviation for the main flow rate at the rings is less than 0.1%.

Regarding the rings and their previously described sub-systems, they obviously require a fixed flowrate to cool their consumptions. In order to evaluate the accuracy of the modeled rings, the simulated results (flow rate in each one of the sub-systems) have been compared with the on-site measured ones as indicated in Table 3 in terms of averaged deviations. It must be noted that some local sub-systems were presenting larger deviation values. It can be observed that the maximum average deviation for the simulated flow rates in three of the rings is about 6.5% corresponding to the Service Area.

Nevertheless, the Booster Ring shows a larger deviation that can be explained by the fact that the measured data is not reliable due to a detected calibration problem of its flowmeter. As a result, the 23.7% deviation does not represent the actual goodness of the Booster Ring's model. It must be noted that this flowmeter issue does not take place in the other three rings.

FLOW DISTRIBUTION		Opening of the S16 exit valve	Opening of the S01 exit valve
180º Circulation	Inlet flow	100%	100%
	Outlet flow	100%	100%
360º Right Circulation	Inlet flow	100%	0%
	Outlet flow	100%	0%
360º Left Circulation	Inlet flow	0%	100%
	Outlet flow	0%	100%
360º Right - Left Circulation	Inlet flow	100%	0%
	Outlet flow	0%	100%
360º Left - Right Circulation	Inlet flow	0%	100%
	Outlet flow	100%	0%

Table 1. Studied Flow Distributions

Pump Group	Q_{CELLS} [m³/h]	Q_{SIM} [m³/h]	% dev.	n_{CELLS} [min⁻¹]	n_{SIM} [min⁻¹]	% dev.	$Pimp_{CELLS}$ [bar]	$Pimp_{SIM}$ [bar]	% dev.
P09 (BO)	28.60	28.60	0.0	2600	2550	-2.0	10.20	10.22	0.2
P08 (SR)	271.00	271.10	0.0	2582	2458	-5.0	10.20	10.17	-0.3
P10 (SA)	200.00	200.10	0.1	2737	2793	2.0	10.00	10.17	1.7
P07 (EA)	16.20	16.20	0.0	2516	2355	-6.8	7.50	7.09	-5.8

Table 2. Comparative Analysis between the Real Measurements and the Flowmaster Simulated Results.

The Optimal Flow Configurations

The presence of air in pipelines may cause instabilities of the water flow. To avoid air problems in pipelines it is widely accepted that minimum flow velocities are required above 0.5 m/s.

In this work the five possible flow distribution in the main pipe rings has been modeled (as is detailed in Table 1). The simulations results show the map of the water flow velocities and allow quantification of the zones where the velocities are lower than 0.5 m/s. Then the recommended 360º flow distribution is the one that minimizes the lower map with velocities respect to the case 180º circulation. Table 4 indicates which one of the four possible 360º flow distributions is the optimal for each ring and the percent of improvement for both the inlet and return flow distributions through the main ring pipes.

RING	Average flow rate deviation [%]
Experimental Area	3.60
Booster	-23.74
Storage	-3.19
Service Area	-6.48

Table 3. Average Flow Rate Deviation of Simulated Value to Measured Value in Each Ring.

RING	Optimal flow distribution	Inlet flow improvement [%]	Return flow improvement [%]
Experimental Area	360° Right Circulation	60	58
Booster	360° Right - Left Circulation	60	40
Storage	360° Left - Right Circulation	33	33
Service Area	360° Left Circulation	43	43

Table 4. Optimal Flow Distribution for Each Ring and Percent of Improvement

The values shown in Table 4 are calculated with the following expression:

$$\textit{Improvement} = \frac{100\,|N_{opt} - N_{180}|}{N_{180}}$$

Where N_{opt} and N_{180} are the number of pipes with flow velocities lower than 0.5 m/s in the optimal and in the 180° configurations, respectively.

Figure 8 illustrates the evolution of the flow velocity along the EA ring's inlet flow main pipe caused by the 180° and 360° circulations. Whereas almost all of the EA ring's sectors have velocities lower than 0.5 m/s (shown in red) when the flow distribution is 180°, the 360° current circulation restricts these undesirable velocities to less than a half of the EA ring. However, there is obviously a zero velocity point next to the closed valve (indicated by the blue cross) but the good point is that it is located relatively far from any sub-system. Therefore, it is clearly observed the fact that the flow distribution change from 180° to 360° entails a significant velocity rise in most of the pipe sectors.

Conclusions

Thanks to Flowmaster 1D Thermo-fluid simulation software, ALBA Synchrotron has been able to improve the fluid dynamic behavior of the cooling system consumption rings.

Actually, each ring has been modeled with a high level of detail of its local consumptions. The accuracy of the model has been validated with real operation data. The resultant models have allowed for the study of the rings' original flow distribution as well as all the alternative possible circulations. As a result, for each ring it has been identified that the 360º flow distribution make it possible to increase those deficient velocities that take place in the original configuration (180º circulation).
The suggested 360º circulations have reduced these undesirable velocities by around 49% on average. Consequently, the cooling system's reliability has been significantly increased.

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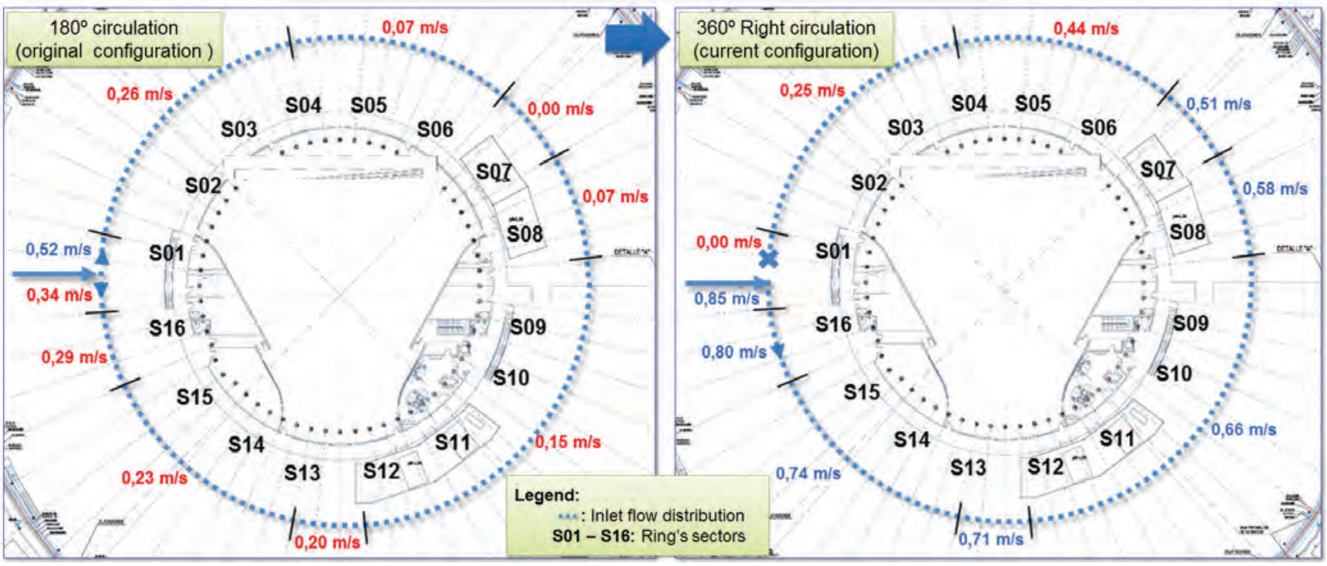

Figure 8. Velocity along the Experimental Area ring's inlet flow main pipe due to the 180º circulation (left) and to 360º current circulation (right).